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ABSTRACT

Lack of attentional control--inability to concentrate--has often made the difference between successful and unsuccessful performance on the part of athletes. Attention is controlled neurologically by a very complex interaction of a large portion of the cerebrum and is not localized to any one structure. The mechanism involves a memory retrieval process to judge the pertinence or meaning of stimulus inputs and thereby decide upon whether or not attention should be allocated to such inputs. Biofeedback technology suggests a way in which the attentional control mechanism could be optimized in the training of athletes. (Author/JD)

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BRAIN MECHANISMS OF ATTENTIONAL CONTROL

Paper presented at the annual conference of the North American Society for the Psychology of Sport and Physical Activity - May 24, 1977, Ithaca, New York.

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ABSTRACT

Attention is controlled neurologically by a very complex interaction of a large portion of the cerebrum; it is not localized to any one structure. The mechanism involves a memory retrieval process to judge the "pertinence" or "meaning" of stimulus inputs and thereby decide upon whether or not attention should be allocated to such inputs. Physiologically, this is accomplished by a hippocampal control of the reticular formation.

The criterion upon which the hippocampus makes this decision is typically the relative emotional or affective value of each input, which is determined by a participation of the limbic system of the forebrain. More specifically, the amygdala and related structures become activated by certain memories associated with the new stimulus input, in a way which accords with the pleasure - pain significance of such memories. This information then is used by the hippocampus to direct the reticular formation to maintain an open "channel" for inputs which tend to bring the organism to optimal (i.e. which are pleasant), and to close channels which tend to enhance

deviation from optimal (i.e. which are unpleasant) and thus switch attention to other inputs.

This mechanism can be interrupted by participation of the frontal lobe, which creates "voluntary" attention by allocating processing capacity according to criteria other than simple pleasure-pain distinctions.

Biofeedback technology suggests a way in which the attentional control mechanism could be optimized in the training of athletes.

This paper is not to be a general summary of the physiological correlates of attending, but of the mechanisms which govern the organism's state of attention and the principle which this mechanism serves. I will skip over, for example, (1) the dispute over the Sokolovian vs. Groves and Thompson models of habituation in specific and non-specific sensory systems, for, even though habituation does represent a form of selective attention, this process is more of a consequence of attentional control than an intrinsic part of it. (2) I will ignore the current controversy as to whether alpha blocking recorded from the occipital cortex is a sign of information processing itself, or merely of the oculomotor control accompanying attending, as Mulholland and others content. (3) Time will not permit coverage of the evoked potential correlates of attention, such as Donchin's P300 wave, or of (4) the exciting developments in the specialized attentional processes of the left and right cerebral hemispheres, which have been described

by Sperry, Milner, Zangwill and others.

A psychological process on the order of complexity of selective attention is not accomplished by some unitary brain structure which can be conceptualized as the apex of a hierarchial system, and which only needs to be discovered. In fact, the control of attention cannot be localized to any one structure, or part of the system such as the frontal cortex, at all. The Aristotelian approach of analysis into structural units, and the assumption that these possess unique functions no longer applies in brain physiology; the idea of a "locus" of attentional control must be replaced by a concept reflecting the dynamic nature of a total system in pursuit of a balanced state. Vygotsky (1960) in fact believes that environmental demands may take previously independent brain areas and tie them together into a sort of an "ad hoc" functional system. Such flexibility fits very well with Turvey's view of the system as a coalition, in which ascendancy may shift from one member to another, and in which even exteroceptive events are considered a part of the system. These ideas reflect the modern view of neurophysiology of many brain scientists, including Bernstein, Pribram, Luria and Eccles.

So to understand attention, one must develop a model which comprehends every part of the system, that is, which is a product of synthetic as well as analytical thinking. Since we are looking for a mechanism of attentional control--which is to say the management of attentional state as a generative or efferent process--we are dealing with a function most highly developed in man, and perhaps even unique to man. Therefore, in terms of methodology, investigators have had to rely, in the final analysis, mainly upon surface recordings, neurological and neurosurgical cases, and, alas, phenomenological reports.

With this perspective in mind, I would like to present the outlines of a current neuropsychological model of attentional control which has been pieced together from several less comprehensive theories, as well as from the research literature.

The reticular formation of the brainstem, midbrain and thalamus regulates the state of consciousness and attention of the organism by its tonic and phasic activation of the cortex, as summarized by Magoun (1963). This influence is both non-specific, and modality-specific or specific to only a particular behavioral system. But the reticular formation does not itself decide upon the output it produces. Instead, it is controlled by three main types of events: (1) Primitive metabolic and

instinctual homeostatic events, such as hunger, sex drive, etc. (2) Exteroceptive stimuli, which result in a specific pattern of reticular activity depending upon previously stored associations, and (3) Intentions and readiness, mediated by corticofugal tracts from frontal cortex, or in the case of specific readiness, from the primary sensory receiving areas (Luria, 1973). In reality, it may be the case that the third of these, intention, never occurs without some prior exteroceptive input and memory search, which leads to the interesting possibility that volition may be viewed as ultimately arising outside the organism, as Sir John Eccles (1963) has suggested.

The principle upon which the reticular selection of input for projection to the cortex operates is the significance, meaning (Mandler, 1976), or pertinence (Norman), of the input. Exteroceptive stimuli for which memories do not exist (and we refer to such stimuli as unconditioned), or which past experience has determined to be associated with survival or affect (and we call these conditioned stimuli) possess significance, and thus capture attention, or processing capacity. In the case of the former, the mechanism is pre-wired. A loud sound such as an unexpected gunshot at close range requires no past experience to flood attentional capacity. All other stimuli, in order to capture attention, and, as Mandler sees it, consciousness

as well, can do so only after memory stores have been consulted and a meaning analysis completed. Thus, the reticular formation is under the exquisite control of the complex mechanism which evaluates each input in terms of its stored associations. Associations are developed through conditioning, which depends upon the affective (pleasure-pain) properties of the stimulus for its occurrence. Therefore, a brain theory of attentional control cannot be elaborated without acknowledgement of the central role of the mechanism of memory, which in turn functions only with the cooperation of the mechanism which gives rise to emotion. The participation of emotion in memory is integrated by the limbic system, to which we will now turn.

The hippocampus is the most important limbic structure in the control of attention by memories. It receives its major inputs from cingulate cortex, entorhinal cortex, all sensory association areas of cortex, and amygdala via the septum. It thus appears to have access to all stored associations and affective responses. Its major output is to the reticular formation via the hypothalamus. The connections suggest that it draws upon affective responses to a stimulus in order to decide upon its selection for further attention. Caution must be observed, however, in making physiological interpretations of anatomical pathways. Information codes in the brain are not sufficiently understood to determine whether a given linkage between two structures

carries imperative, declarative, or interrogatory signals. In addition, reticular activation diffuses back to the limbic system via the cortex, and there is a lot of reverberation throughout the system, making it difficult to claim that any one structure is controlling any other. However, taken together, the anatomical and physiological evidence supports the view that: the hippocampus exerts control over attention whenever a mismatch occurs between stimulus and stored template; this mismatch consists of a discrepancy in the affective valences of stimulus and relevant memories; and the hippocampus is required for maintaining attention, attitude, or set long enough for consolidation of the change in the template to occur, which we call learning. This explains why during information processing the hippocampus often produces synchronized theta waves while the cerebral cortex is desynchronized. The hippocampus, while producing theta, is relaxing its inhibitory control over the reticular formation. This directs memory consolidation by setting up a reverberation between the cortex and corebrain areas, permitting attention and learning to occur. For example, after the reinforcement on a learning trial, amount of theta is directly correlated with retention for up to 30 minutes (Landfield et al, 1972), and hippocampal

electrical stimulation which disrupts theta during this interval interferes with consolidation (Shinkman et al, 1972). On the other hand, when change in the organism's "attitude" toward the stimulus is not required, the hippocampus remains desynchronized, maintaining its tonic inhibition of the reticular formation, so that processing capacity, including conscious attention, is not inappropriately diverted to the input. This may occur even though the cortex itself is desynchronized by the stimulus. The frontal cortex is involved in this construction of a template which requires sustained attention, as evidenced by the well-known data on delayed response deficit in frontal animals, and hyperdistractibility with failure to habituate in frontal patients (Konorski et al, 1964; Brutkowski, 1957 and 1966). The roles of the frontal cortex and hippocampus, however, are quite different. Luria (1973) found that instructions to a patient with a pre-frontal lesion to attend to a stimulus does not elicit normal EEG changes and orienting responses which signify attention to that stimulus. This is true even if the orienting responses to unconditioned stimuli is intact. In contrast, such instructions can compensate lesions in the hippocampus. That is, instructions to attend in a patient with hippocampal damage will elicit selective attention. Thus, a "voluntary" form of attention mediated by the frontal to reticular system can momentarily take over the function normally performed automatically by the hippocampus. However, pre-frontal

ablation completely removes the voluntary, conscious, form of attentional control. Only if the frontal lobes are intact can a perceptual or motor program requiring sustained attention to a template or goal extracted from memory be carried out. In addition, there is an orbitofrontal-amygdala-medial hypothalamus circuit which tends to generate somatic and visceral arousal (unpleasure), and a lateral frontal-amygdala-lateral hypothalamus circuit which tends to inhibit such arousal. The influence of these upon the reticular formation completes a highly intricate reverberating circuit, in which the amygdala regulated the internal state of arousal of the organism, and the hippocampus coordinates this with the selection and use of exteroceptive stimuli in action plans. All outputs of these mechanisms go to the reticular formation and thence to the basal ganglia and cortex, and ultimately return to the limbic system, incorporating any changes in state since the last reverberation. In the course of performance of a motor skill, if attention to the present stimulus is not resulting in a better and better match with the template or goal of the movement, arousal is not reduced; associated negative affect, or "unpleasure," to use Weil's (1974) term, occurs causing ANS arousal, and prompting hippocampus to inhibit the on-going attentional set through reticular arousal and initiate a new one. On the other hand, if attention to present stimuli during performance does not result in

an error signal, arousal is reduced, a pleasant subjective state occurs, and the hippocampus continues to inhibit non-specific reticular cortical activation, and to potentiate the basal ganglia's production of the on-going motor pattern.

I would like to briefly focus upon this latter situation in which attention is effectively sustained to relevant stimuli, in describing some of the studies on the role of the frontal lobes in attentional control. If you require a subject to attend continuously to a perfectly predictable anticipated event in a simple reaction time situation by requiring him to respond as quickly as possible to the second of two stimuli separated by a constant foreperiod, there appears a slow negative shift in the frontal EEG which increases in amplitude until feedback from the response occurs (Weinberg, 1972; Pribram et al, 1967). This wave, the Contingent Negative Variation (CNV) or expectancy wave, occurs if any sensory discriminative response, overt motor response (self-paced or in reaction to a stimulus), or even a simple expectancy, is present (Vaughan et al 1969; Donchin et al, 1972). Pribram et al (1975) assert that this wave is a recruitment of frontal neurons in a readiness to process infomation. This interpretation is supported by studies by Tecce et al (1969) and Kakagiet al (1975) which found CNV

amplitude to be positively correlated with speed of reaction to a stimulus. A demonstration by Walter (1969) suggests that the subjective counterpart of this readiness to process information may be called willful attentional control. Walter had his subjects press a key to turn on a TV monitor showing an interesting scene, while recordings of the frontal CNV were taken. He then linked the monitor to the subject's frontal brain activity in such a way that a certain amplitude of the CNV would turn it on. The subject found that his intention to press the button turned the TV on, and that he could keep it on as long as he didn't become distracted from "willing" the button press. In other words, willing a motor act may be identical to keeping a given information processing channel open. This may be interpreted as a holding of a model of the movement in short term operational memory by active, attentive process, and is reflected in the CNV. Also the location of the CNV varies with the task (Kutas et al, 1974; Pribram, 1971), suggesting that the readiness has some specificity.

Tecce (1976) has developed the view that the focusing of sustained attention mediated by the frontal lobes reduces activity in the arousal system, thus reducing distractibility, and that the CNV is positively related to such sustained attention. This is supported by anatomical evidence of

abundant fronto-amygdala and fronto-reticular pathways (Nauta, 1964). If Tecce is correct, there are important implications for athletic performance, for it delineates a physiological mechanism for the self-regulation of autonomic functions, which so often interfere with skilled performance. Moreover, it suggests a technique, the CNV, to monitor such control. It must be kept in mind, however, that the frontal neocortex does not originate attentional control, nor is it at the top of some hierachical system. It is regulated by on-going limbic, reticular, and basal ganglia activity in a complex reciprocal fashion.

With our recent knowledge of the physiology of attention, it is now possible to develop training in attentional control as a part of physical education. The CNV could be recorded, and employed in a biofeedback paradigm to improve general attentiveness and reduce excessive arousal. According to Luria (1973) this should also improve the smoothness of the "kinetic melody" of an act, which is highly sensitive to loss of attentiveness. Also, in view of the apparent topographical specificity of the CNV, we could direct a subject's attention to certain regulatory aspects of a skill, and divert it from non-regulatory inputs, by monitoring the CNV. It is possible that we might be able to train subjects to adopt either a propositional-sequential or appositional-simultaneous cognitive mode, depending on motor task demands, by providing them with feedback about

whether the CNV is larger in the left or right hemisphere respectively.

Lack of attentional control -- inability to concentrate-- has often made the difference between successful and unsuccessful performance; it can be a constant source of frustration for the less skilled, and can occasionally intrude upon the performance of even the best athletes. Our knowledge of its workings is only beginning to take shape in a comprehensive way. The mechanism is of a very high order of complexity, and the present paper has not presumed to explain it in its entirety. Hopefully, however, the data will permit this in the near future.

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